On the Desirability of Integrating Research Methods into Overall Systems Approaches in the Training of Engineers: Analysis Using SSM

Abstract — *The development of systems practitioners in engineering has revealed the need to bridge between the research methods teaching of engineering management and soft systems approaches. Whilst action research might be viewed implicitly as the research strategy of systems practice we argue that engineering management research methods, in the broadest sense, require practical linking with soft systems approaches in order to meet the needs of research projects that span the boundary between engineering and the social world. Our observations arise from the experience of delivery of an Engineering Doctorate (EngD) in Systems Programme. We explore this need for bridging using Soft Systems Methodology (SSM) as a reflective device. We argue from our analysis that systems education for engineers needs to focus on ten key aspects that will be instrumental in bringing about the wider use of soft systems approaches to engineering systems. We present these conclusions using a process-oriented view.*

Keywords — *Soft Systems, Soft Systems Methodology, Research Methods, Systems Engineering, Action Research, Engineering Education*

1. Introduction

The Industrial Doctorate Centre (IDC) in Systems, a collaboration between the University of Bristol and the University of Bath, offers an Engineering Doctorate (EngD) in Systems Programme which is aimed at high-calibre engineers from graduate level to early/mid-career stage with the purpose of developing the systems-thinking capabilities of future leaders in industry. The portfolio of projects is diverse with more than 70 projects and growing at ~12-15 per year, and involving more than 35 companies representing both Small and Medium-sized Enterprises (SMEs) and multinationals. Projects span industrial sectors including defence and aerospace, rail, transport, energy production, construction and the water industry. They include applications to product development, process improvement, methods and tools development, and decision support. All the projects aim to apply systems thinking in engineering companies to enhance performance and deliver better outcomes in areas such as safety, quality, sustainability, and innovation.

Students on the Programme are referred to as *Research Engineers* and whilst this paper focuses on an analysis of a particular EngD programme we overload the term to refer to any early/mid-career stage engineer beginning to confront methods that deal with the social rather than purely technical domain. The emergence of the EngD as a pre-eminent mode of postgraduate education for engineers is a consequence of the 1990 Parnaby Report to the Science and Engineering Research Council (SERC).

Current teaching is based on approaches drawn from systems engineering, engineering management, systems modelling, and systems thinking, and seeks to integrate across them in order to meet both the specific needs of the projects and the necessity for appropriate academic rigour in doctoral level research in engineering. Pedagogic development itself is needs driven, based on feedback from Research Engineers and industrial partner organisations. In the early stages of teaching research methods, we introduce Research Engineers to the philosophical assumptions, paradigms, and strategies associated with different research traditions from physical, applied and social sciences. All are potentially relevant when researching and intervening in the complex problem contexts that arise at the boundaries between the material artefacts of engineering and the social world in which they are conceived and used, and in which the projects on this programme are focussed. Therefore, the motivation behind the paper and its overall purpose is to provide a detailed description of our solution to the problem of integrating, or bridging, research methods and systems teaching at the doctoral level for Research Engineers and which we see as *necessary* in order for them to be equipped to tackle problems in this context. An alternative expression of this purpose is the need to bring about soft systems awareness in Research Engineers.

Note that in this paper we refer to these problem contexts as socio-technical systems although we are aware that this is not in keeping with the original definition originating from Emery and Trist at the Tavistock Institute, but is consistent with more common usage in the Systems Engineering community; for example as used by the Large Scale Complex IT Systems (LSCITS) initiative (Baxter, 2011).

Further support for our approach is provided by relating our need to bring about soft systems awareness to a similar need arising from management schools expressed as "*Teaching Soft O.R., Problem Structuring Methods, and Multimethodology*", (Mingers and Rosenhead, 2011). We have expressed our need using the term "*soft systems*" since this has been a preferred term on the programme since its inception, but Soft OR and Problem Structuring Methods (PSMs) have broadly equivalent meaning (Mingers, 2011). Of the different approaches described in this special edition (Mingers and Rosenhead, 2011) it is the one based on experiential learning through role-playing (Hindle, 2011) that resonates most closely with what we see as needs in engineering education. However, our primary focus on this programme is to bring about a general awareness and understanding of soft systems and we have yet to adopt a specific method and approach.

2. METHOD

This paper uses an analysis of Checkland's Soft Systems Methodology (SSM) (Checkland, 2010, Checkland, 1999, Checkland and Scholes, 1999, Checkland and Poulter, 2006) to reflect on the needs of engineers as they transition through the research methods teaching, originating in engineering management, and on to learning about soft systems (our definition follows). This reflection and discussion is developed from the practical experience of the authors in the delivery of research methods and systems teaching to six cohorts of Research Engineers on the EngD in Systems Programme over the period 2006-12. We have also reviewed reflective logs produced at an early stage in the programme by Research Engineers to formulate their initial proposals for addressing their individual projects, including integration of basic research methods into any chosen systems methodology. The logs contribute to initial research planning discussions with industrial sponsors and academic supervisors. To structure our reflection, we relate and link SSM to the research methods teaching currently delivered on the EngD in Systems Programme and locate it within the framework we use for suggesting an overall systems research philosophy and design strategy that Research Engineers can use in a given problem situation.

3. Rationale for Teaching Research Methods for Engineers

The majority of systems engineering research sits within a positivist research tradition and there has been little evidence for explicit use of a *research method* or even an acknowledgement of the philosophical stance in much of the published research that could be considered as originating from systems engineering (Valerdi, Brown and Muller, 2010, Brown, 2009). The nature of the EngD in Systems Programme is such that it should more accurately be viewed as applying systems approaches to contexts grounded in engineering; which encompasses systems engineering whilst broadening its coverage to projects based on engineering disciplines that would not normally be considered within systems engineering practice, such as civil engineering, although this is developing area (Elliott et al., 2011). However, once the engineering system, or hard system, under study encompasses elements of the social world then its behaviour will be strongly determined by human intentionality.

Therefore, having moved beyond the study of hard systems, the engineer studying any socio-technical system *must make explicit* their prevalent research paradigm, approach and strategy. The socio-technical system *under study* needs further qualification too. Research may embody any or all of analysis, design and intervention. It is the last of these, intervention, which is the purpose of Problem Structuring Methods (PSMs) (White, 2009, White, 2006, Rosenhead, 1996, Mingers and Rosenhead, 2004, Eden and Ackermann, 2006), although of course intervention may require prior analysis and design. The literature on PSMs (including SSM) lacks discussion on how research methods and strategies should be incorporated, when that is necessary to achieve necessary *rigour* in doctoral-level research. Checkland also hints at this when discussing how the results from SSM should be "*recoverable*" by any outsider interested in critically scrutinising the work and following it to see if they agree or disagree with the findings (Checkland, 1999).

Therefore, the question of how to *bridge* between research methods and systems interventions is quite pertinent to a Research Engineer who is planning to use a PSM such as SSM, as part of their research. We believe this needs to be done rigorously, and rigour here is meant to convey the practitioner's goal in trying to improve complex socio-technical systems performance and thus has very practical grounding – it is not mere academic baggage or formalism. We see this as underpinning the following requirements that are fundamental to achieving that goal:

1. Giving the best chance of getting the choice and implementation of an intervention *right first time*,
2. Ensuring the intervention is as robust as possible and *resilient* to changes and errors in assumptions,
3. Forming the best platform/data for optimal *learning* to e.g. improve on the processes of developing transitional objects such as purposeful activity models, and
4. Solving real problems in industrially relevant timescales, where investment in the extra time needed for *up-front* rigour should offer payback in terms of less time later e.g. optimal survey sampling and tight holon/model construction.

Checkland's SSM and other PSMs offer this *practical rigour* in a high level *process* sense, and SSM is perhaps the highpoint here, but the whole use of a PSM in an engineering research context is likely to fall down if this practical rigour does not integrate at a *lower* level in the individual steps, i.e. with use of appropriate research approach, strategies and methods.

4. SOFT SYSTEMS METHODOLOGY IN RELATION TO ENGINEERING EDUCATION

In broad terms, SSM can be characterised as action research with its own features and characteristics, strengths and weaknesses. If one chooses action research as a research *strategy* based on the model adapted from (Saunders, Lewis and Thornhill, 2009) then SSM offers a *process* for tackling a problem situation, assuming the problem is of the class suitable for using SSM. It is thus an approach for implementing one of the basic research *strategies* available to systems researchers, whilst at the same time can be viewed as a PSM in its entirety. Jackson positions SSM clearly as appropriate for problem contexts that are plural/simple and plural/complex in his System of Systems Methodologies (SoSM) (Jackson, 2000, Jackson, 2003). It can be used alone where appropriate, or in conjunction with other PSMs (in whole or part) as a multimethodology strategy (Mingers, 2001, Schein, 1996, Midgley, 1997b, Midgley, 1997a). By itself, SSM has the major strength that is offers a logical process for engaging all stakeholders and coming to an agreed initial action or intervention for improvement in any system, which accommodates different interest groups – rather than a blind trial with no rationale behind it.

4.1. Parallels with the development of SSM

SSM originally developed in response to difficulty in applying the systems engineering approaches used in traditional engineering and science problems (in hard physical systems) to business and organisational problems in human activity systems. The programme at Lancaster University was conceived from the very beginning as one of action research (Checkland and Jenkins, 1974). There was an early acknowledgement that the education process of the programme, its pedagogy, was characterised as "*learning by doing*" (*ibid*). Later work argues for the validity of this approach (Checkland and Holwell, 1998).

The consequence of using an action research strategy from the outset allowed for a reflective critique of the results from applying systems engineering techniques to "*(human) management situations*" (Checkland, 2010). They learned from the difficulties and failures and this led eventually to the development of what became SSM. Checkland in his reflections (*ibid*) draws attention to the *accountability* of the researcher in action research and that the

> *"…researchers are not outside observers of the situation being addressed but are accountable participants in it."*

We are struck by similarity. This observation mirrors exactly the nature of the EngD Programme in Systems. The Research Engineers are *embedded* within the partnering organisation for ~75% of the 4 year programme and accountable for the delivery of the project. There is a novel three-way relationship between the sponsoring industrial company, the University, and the Research Engineer, and that he or she is treated *as if they were an employee of the company*. This feature of the programme is actually common to a number of Industrial Doctorate Centres that offer Engineering Doctorate Programmes and a direct consequence of the Parnaby Report.

Each of the individual projects can be viewed as instances of action research, although until recently there was not an explicit acknowledgement that the overall programme itself is action research. This has recently been addressed by a new programme of research at the University of Bristol into Systems Practice in Engineering (SPiE), designed to synthesise across the EngD in Systems Programme and reproduce the environment that Checkland and colleagues achieved at Lancaster University (Burger and Yearworth, 201x).

4.2. Timing the introduction of Soft Systems teaching

Jackson characterises SSM as an approach that

> *"…gives pride of place to people, rather than technology, structure or organisation. Thus, its primary area of concern is perceptions, values, beliefs and interests and it accepts that multiple perceptions of reality exist and come into conflict" (Jackson, 2000).*

Whilst agreeing with this entirely we believe the introduction of the idea that multiple perceptions of reality exist needs to be introduced with some care such that Research Engineers are ready to accept the need for this interpretivist stance. Therefore, before we get to this position we start on the programme along a slightly different track with the work of (Rittel and Webber, 1973) who gave a persuasive account of "*wicked*" problems in complex systems. Rittel and Webber pointed out, quite strongly, the deficiencies of the sequential, engineering-based *hard systems* approach that involve precise objectives, control of variables and reductionist approaches to *wicked* human activity problems – for example urban planning, design and public policy making. In their paper, they go further and provocatively suggest that many/most of the problems and mistakes made in society, government and professional services have been caused by a misguided adherence to the *engineering* approach of hard systems thinking in social contexts where it has been shown not to work, e.g. RAND's Systems Analysis based approaches in New York City in the early 1970s described in (Rosenhead and Mingers, 2001). This critique mirrors Checkland's own reservations directed towards "*traditional OR*" (Rosenhead and Mingers, 2001). Therefore, *before* the "*multiple perceptions of reality exist*" foundation of SSM can be fully appreciated, the failures of an engineering viewpoint that ignores this have to be understood.

For engineers recruited to the EngD in Systems Programme, the work of Rittel and Weber, and others such as (Conklin, 2001, Ackoff, 1981), is their first exposure to a literature that challenges their existing engineering mind-set and research skills, developed in their first degrees and possibly through experience gained as practicing engineers, and posits that these will not be enough to deal with the complexities of socio-technical systems. It is really only since the mid 1970's that *hard systems* approaches to problem solving in complex systems have been recognised as being deficient, and engineers (and others) have been confronted with the need to understand and adopt an entirely different rationale to situations in which people are involved.

Despite the fact that 30 plus years have elapsed since then, there has been little written for engineers that adequately addresses this need. There are exceptions, Hitchens provides adequate coverage of soft systems methodology written from a Systems Engineering perspective (Hitchins, 2007). In the civil engineering domain, and in direct response to the 1998 Egan Report into problems in the UK construction industry, (Blockley and Godfrey, 2000) provide a very practical approach based on a process-based view of systems (Blockley, 1999, Blockley, 2010).

It is clear from the limited amount that has been written to address this need that there is more work to be done. A recent and promising development is from the International Council on Systems Engineering (INCOSE) through its Systems Engineering Body of Knowledge (SEBoK) project (INCOSE, 2012) and its Systems Science Working Group (SSWG), which is a joint activity with the International Society for the Systems Sciences (ISSS). Both of these have sought to increase the awareness of soft systems in the wider Systems Engineering community. The EngD in Systems Programme also introduces Research Engineers to Schön's reflective practice (Schön, 1991) and which is specifically focussed on delivering "*improved handling of problems with often occur at the interface between difficult technical problems and human and organisational issues*" (Blockley, 1999). However, these isolated activities need to become a more mainstream part of engineering education.

4.3. An axiomatic formulation of SSM for engineering

The difficulties encountered by engineers in grappling with soft systems concepts following a predominantly hard systems training and education should not be underestimated. Feedback and reflective logs produced by our research engineers indicate the major realignment of their thinking required, they also show the "*shock*" of finding their tried and trusted methods are deficient in complex situations and the time required to fully absorb the new thinking involved. The following extract from

(Yearworth, Edwards and Rosenberg, 2011) illustrates the challenge to the supervisory team:

"Significantly, most Research Engineers admit to a rather superficial understanding of their 'systems' and purposes of their project at the time of undertaking the initial research methods training. However, all express a strong desire to more fully explore their systems and problem situations as a key first step. Several indicate how the training has given them an entirely different perspective on how to make a start on their work.

Overall, Research Engineers' reflective logs indicate a very intense learning experience, which shakes them up to some extent and fundamentally challenges their existing worldview as engineers in relation to real world systems and systems research.

Categories emerging from the above analysis fall into two broad groups

1. *Complexity of the problem, stakeholders and system boundary, and the alignment of research questions with the industrial problem being solved, and*
2. *Dealing with countercultural and counterintuitive ideas from phenomenological and mixed research paradigms.*

The first of these might be considered the 'bread and butter' of systems research. The second emerging category is more problematic and can be broken down into a set of concerns as follows:

a. *Rigour and validity of phenomenological research approaches e.g. the perceived weakness of induction and unreliability of qualitative data analysis* *b. Dealing with Action Research and its links with system intervention approaches*

c. Discomfort of having to justify phenomenology and qualitative research methods in an engineering company

d. Social skills necessary to conduct qualitative research and apply appropriate techniques e.g. grounded theory.

The range and scope of projects represented on the programme means that a Research Engineer may identify with any one or more than one of these categories and issues. It is the concerns about phenomenological research in an engineering context that generates the greatest supervisory load. Also, the apparent lack of integration so far in the current literature between generic research methodologies and broader systems intervention approaches provides a challenge in order for Research Engineers to demonstrate intellectual and methodological rigour at all levels of their work."

With this in mind, we are continually searching for language and concepts to help accelerate learning and provide engineers with tools to discuss the ideas with industrial and other stakeholders. A good example of what we have found useful is given below. This list provides an axiomatic formulation of SSM and is presented here as a slightly modified version of a briefing note from the Cambridge University Engineering Department (CUED, 2011):

1. Problems are constructs of an individual's mind and therefore do not exist independently of human thought. These constructs are defined by an individual's "*world view*"; therefore it is important to look at worldviews as a basis for understanding any individual's statement of a problem.

2. The problem field is invariably messy – many potentially related problems and sub-problems can interact in any given system.
3. "World views" mean that different but equally valid interpretations of the real world can exist among individuals.
4. As a corollary of the first axiom – solutions to problems are also intellectual constructs and no problem exists "*in isolation*."
5. Improvements and beneficial interventions in any system problem are most likely to come through sharing of "*perceptions, persuasion and debate*. Analysts/researchers/problem solvers should be "*interactive/therapeutic*, *not expert*".
6. Furthermore, analysts cannot be "*divorced from the problem*" and they cannot act as objective "*outsiders*" as in engineering hard-systems research.

This axiomatic presentation of the principles of SSM resonates with our experience of teaching engineers (Yearworth, Edwards and Rosenberg, 2011) and appears highly valid. We suggest the second axiom here should probably come first, in that it is messy problem contexts that provide the underpinning need for a PSM in the first place, and that as soon as the problem need is examined then the impact of the first axiom becomes apparent. Although the fourth axiom is stated as a corollary of the first we believe that in an engineering context this requires reinforcement through more of an appreciation of the failures arising from hard systems thinking as we discussed previously in §4.2. For example, general guidelines emerging from the Royal Academy of Engineering in the UK support the view that solutions do not exist "*in isolation*" but do not go as far as to support the idea that a solution is also an intellectual construct (Elliott and Deasley, 2007). Axiom five then follows from the notion that a solution is an intellectual construct and is therefore as contested as the problem itself. A recent case study highlights this point and suggests that there are non-codified uses of PSMs by engineers (Yearworth, Dunford, York and Godfrey, 2012) and which illustrate the need to facilitate "*sharing of perceptions, persuasion and debate*". Axiom five perhaps presents the most difficult proposition for an engineer to digest; engineering is all about expertise and role of engineering as an engaged "*interactive/therapeutic*" process as opposed to expert and consultative is still to be worked out. However, as stated in §4.1, the EngD in Systems Programme deliberately positions Research Engineers in an engaged situation where expertise is likely to be viewed as less relevant (Burger and Yearworth, 201x).

4.4. Basic (classical) SSM

SSM is not a research method, however it does provide a high level, overall thinking and engagement process which provides a process for bringing diverse human interests together and looking for sensible compromises on the way forward – but not necessarily consensus.

Figure 1 illustrates the 7 stage ' journey' in the application of the classical SSM approach in action research – as outlined by (Checkland, 1981) and reproduced verbatim by (Jackson, 2003) and who writes "*Checkland no longer favours it - but it is still frequently used*" and uses this form to describe the methodology. For this reason, we too have chosen to use this representation for this paper. In Checkland's 30 year retrospective (Checkland, 1999) he uses a slightly different version[1] and it is these different and evolving versions that contribute to some of the difficulty in interpretation.

Figure 1. Schema for *classic* SSM adapted from Figure 10.2 in (Jackson, 2003)

Like many systems approaches, the heart of SSM is a comparison between the real world as it is and some mental, conceptual, models of the world as appear in peoples' minds. Those involved are therefore required to move in and out of the real and the conceptual, systems thinking, world as they progress through the approach. Out of this comparison comes a better understanding of the real world system and ideas/options for improvement (interventions).

4.5. Later developments in SSM

According to Checkland's comments in the retrospective section of (Checkland, 1999) the above seven stage SSM model has proved resilient and has a sequence which unfolds logically. However, as a result of practice and application experience in the years since its introduction in 1981, it was considered (around the early 1990s) to be no longer able to capture the flexible uses of SSM that were emerging.

This led to two later refinements and reformulations:

- **The 'Two Streams' model of SSM**. This placed increased emphasis on the two logical strands of analysis. Firstly, analysis based on the conceptual models of stakeholders to surface ideas for systems interventions. Secondly,

[1] And indeed again at his keynote speech at the 55th Meeting of the International Society for the Systems Sciences in 2011.

a cultural and political strand to enable judgements about accommodating different world-views and agreeing an acceptable intervention on this basis.

- **The 'Four Main Activity' Model of SSM**. This is seen as the current contemporary form of SSM and subsumes the seven stage model into an (implied) set of four activities

    a. Finding out about a problem situation, including culturally/politically

    b. Formulating relevant 'purposeful activity' models

    c. Debate, using the above models, to identify a) desirable and culturally feasible action/change which would improve the situation and b) accommodation between conflicting interests which enables action/change to be taken

    d. Taking action in the problem situation to bring about improvement

The following discussion is appropriate to activities within both the original (classical) version of SSM and later, contemporary versions.

5. MOVING FROM RESEARCH PARADIGM TO SOFT SYSTEMS FOR ENGINEERS

In teaching basic research methods on the EngD in Systems Programme (Yearworth, Edwards and Rosenberg, 2011) we introduce the paradigms, strategies, concepts and techniques utilised in typical business and management research and drawn from (Hussey and Hussey, 1997, Saunders, Lewis and Thornhill, 2009, Bryman and Bell, 2003) amongst others. The two pure research paradigms dominating this literature are positivism and phenomenology. These are defined in terms of the five underlying philosophical research assumptions as shown in Table 1.

It is important, in this context, to distinguish between different uses of the word *paradigm*. Here we are concerned with the technical research meaning provided by (Kuhn, 1962) and discussed by (Jackson, 2003). The word paradigm in this context refers to a tradition of research regarded as authoritative by a particular scientific community – for example pure science, applied science or social science. It is the set of ideas, assumptions and beliefs that shape and guide that scientific research activity. In contrast to this, workers involved in the development of systemic PSMs are often concerned with wider *sociological paradigms* – in order to assist managers in trying to improve the operations, services or organisations they manage (Burrell and Morgan, 1979, Alvesson and Deetz, 2000). The main sociological paradigms discussed in this context (Jackson, 1993) are functionalist, interpretive, emancipatory, and post-modern; although we are not concerned directly with emancipatory and post-modern paradigms and do not cover their associated methods on the EngD in Systems Programme. We note Checkland's view of equating the objective/positivistic philosophical position with the functionalist sociological stance, and equating the phenomenological research methods with the interpretivist (Checkland, 2006). In particular, the ontological, epistemological and axiological assumptions are strongly and classically phenomenological. In SSM:

- Reality is subjective and is accepted to be seen differently by different individuals
- The researcher is part of that being researched and cannot be divorced from the problem situation

- The negotiations and the whole process is value laden, and
- Research structure emerges during the process. However, in terms of the methodological assumptions – the philosophical basis of the approach starts inductively but can easily switch to a more deductive stance later on. This is an example of synthesis and mixing of paradigms in real world research.

Thus, the application of business research methods within a soft systems approach will almost certainly rest strongly on a phenomenological research tradition and perspective. With this in mind it is useful to emphasise the typical characteristics of phenomenological research outcomes in terms of the basic measures of research *quality* – reliability, validity and generalisability. Results from a soft systems approach cannot be said to be highly reliable – in the sense that another team addressing the same problem would be likely to come up with different models, analyses, proposed changes and actions to improve. On the other hand, a soft systems approach is highly valid – in the sense that it provides an opportunity to appreciate the real richness and complexity of the particular situation being examined and actions emerge based on this. The results from a soft systems approach in one situation or setting are unlikely to be generalisable to another situation or setting without thought and/or more modelling and debate. From this we conclude that for any engineer intending to use a soft systems approach, it would be crucial to discuss and come to a clear understanding of these matters among all parties. This is particularly the case when Research Engineers on the EngD in Systems Programme may need to engage with managers and other stakeholders who are not fully aware the above concepts. Such individuals might implicitly assume that any doctoral level research will always deliver highly reliable, valid and generalisable outcomes and interventions.

The various stakeholders and involved parties are given particular names in SSM – partly to try and differentiate their possible contributions and partly reflecting the initial *consultancy* focus of the approach. Some of these roles often overlap. Stakeholder listing and analysis is probably a sensible way of identifying these roles and individuals and agreeing who is playing what. One crucial question likely to face a Research Engineer is whether he/she has the skills, experience and status to be an SSM facilitator within their organisation. This is discussed further in §6.5.1 below

6. DISCUSSION

Since SSM is essentially a high-level overall thinking and engagement model adopting it for a Doctoral level research project in Engineering requires careful selection, justification and application of detailed research methods, tools and concepts in the various stages, and maybe some flexibility/adaptation of the overall methodology. To illustrate this, we have framed our discussion in terms of the contemporary 4 main activity model of SSM described in §4.5 and selected examples of research concepts and tools which are taught in the EngD in Systems Programme in the following 4 subsections. Further details and reflections on research methods teaching is given in (Yearworth, Edwards and Rosenberg, 2011) and on the role of systems supervision, an essential component in the delivery of the programme, in (Yearworth, 2011).

6.1. Problem space investigation

The first stage activity of SSM involves interactive, relatively unstructured investigation of the problem situation and the rich picture approach (pictures without rules) is promoted as a key tool. However, with the ideas presented in §3, a range of other creative, unstructured or semi-structured approaches are also available – see . For example, the use of metaphors and analogy can be injected to support/replace rich picture diagramming and improve communication of understanding to all involved. Formal stakeholder mapping and analysis in various dimensions (e.g. power, influence, interest, location) and PESTEL techniques can also be important to develop understanding of the cultural/political environment associated with the problem situation.

Checkland and Poulter also acknowledge the need for additional frameworks and approaches to support rich picture building in his latest contemporary account of SSM main Activity 1 (Checkland and Poulter, 2006). These can involve examination of proposed interventions and problem owners (as a way of further understanding the problem situation) and a framework for formal social and political analysis.

Examination of research concepts also suggests other possibilities, particularly the idea of introducing other formal research strategies at this stage, if time allows, to integrate with the overall SSM/Action Research approach. Obvious possibilities include ethnographic strategies - to develop in depth understanding of inner workings of organisational systems and the cultural and political norms involved. Surveys, field experiments and grounded theory may also be considered. Longitudinal research studies to obtain a first understanding of dynamically changing problem situations may also be of importance. However, the question of available time might well arise and could limit the scope for this. Grounded theory approaches have been used in a number of EngD projects so far, for example see (Dunford, Yearworth, York and Godfrey, 2012).

A literature review and scoping/planning such reviews to understand what others have found out in similar problem settings is a crucial initial research tool in this stage.

Skills in scoping, planning, recording and critical reading are taught on the EngD in Systems, as they are central to this.

It is in these early stages of problem space investigation that ethical questions and issues may arise that need further consideration at later points – see below.

6.2. Formulating relevant purposeful activity models

We cover *modelling* in the taught component of the EngD in Systems Programme to allow Research Engineers to access various modelling concepts in line with the research approach adopted and PSM chosen. The discussion below relates to our views and questions about purposeful activity modelling in the SSM approach and how modelling strategies might be extended.

Building purposeful activity models in SSM is not the same as the modelling that engineers have traditionally used for years in hard systems work. We need therefore to take great care in our teaching of modelling as part of the research methods training, which currently follows (Pidd, 2004), to embed ideas of what purposeful activity modelling means in SSM but also how it may or may not relate to other modelling activities with which engineers are more familiar. Purposeful activity modelling is not an easy concept for engineers to absorb. The following covers some key points as they are emerging in internal debates and teaching of Research Engineers involved in working within socio-technical systems. The key point made by (Checkland, 1999) is that SSM modelling is not like hard scientific or operational research approaches – where a model is an attempted representation of some part of the real world which could conceptually be *validated* and maybe used in some predictive sense. SSM purposeful activity models are *intellectual devices* in the mind of an observer, based on a particular world-view, aimed at triggering/structuring debate about the problem situation. They do not attempt to model any aspect of the real world system. They are more like idealistic representations of how a defined "*purposeful activity"* might be pursued in an ideal system – depending upon the world-view of the observer. They are therefore "*personal accounts*" of how the "*work should work*" to achieve a defined purpose (not how it *actually* works), aimed at stimulating, feeding and structuring debate about potential actions to improve. Because of the confusion that the original purposeful activity wording/idea has caused, Checkland eventually arrived at preferring the word "*holon*" (Checkland, 1999).

The detailed processes and recommendations for building purposeful activity models/holons are well documented together with a number of pitfalls based on implementation experience. For example, forcing the model's system boundary to coincide with real world organizational boundaries is a well-known mistake since organizations carry out many purposeful activities not mirrored by organizational boundaries.

Generally, from reading the various accounts, our view is that it may be useful for engineers to consider a holon or purposeful activity model to be more or less equivalent to the better-known concept of an idealized organizational or *business process*. Checkland's discussion strongly suggests this, a purposeful activity model must cover a set of purposeful activities (around 7±2) which link together to describe the observer's view of i) how input (I) is obtained for the process ii) how it is transformed (T), and iii) how the output (O) is dispensed with or handed over internally (to another holon?).

The question then arises – how to represent such a model or process? The suggested approach (Checkland, 1999) is effectively a system influence diagram (although

Checkland does not refer to it as such), which considers activities as "*system elements*" and shows dependencies and *precedences* between these. Thus, the holon shows those that are independent (can be done first e.g. to generate input) and those that are dependent on others. We find this concept to be a useful and necessary link to bridge to our teaching of general systems concepts. The system influence diagram then indicates the journey through the activities to produce the output and monitor/control it.

With this understanding of a purposeful activity model (holon), our view is that the system influence diagram suggested by Checkland is only one of a range of possible ways of representing the holon. Other candidate techniques, again perhaps more familiar to engineers, include process mapping tools, process flow charts, activity flow diagrams and project network charts. We also therefore encourage different approaches drawn from these different knowledge areas. The philosophy is that any representation of the holon, using any coherent approach with which the analyst (the Research Engineer) feels comfortable, is useful so long as it stimulates debate on possible improvement actions.

However, and we are treading cautiously here, there appears to be an implied reluctance in the SSM literature to consider other such modelling techniques for representing purposeful activities/holons. Possibly this is because many of are traditionally associated with hard system approaches which try to model the *real world* and are thus firmly rooted in a functionalist paradigm. However, because many such techniques have multiple uses, this seems to be a limit to creativity and we would want to encourage engineers the broadest thinking on options for purposeful activity model building.

Finally, we are engaging with the question of when or if other, even *harder*, more advanced modelling strategies have a place in SSM. By this we mean things like causal loop diagrams, systems dynamics modelling (Forrester, 2007, Forrester, 1958, Sterman, 2001, Sterman, 2000), mathematical modelling using MATLAB (Chaturvedi, 2009), Hierarchical Process Modelling (Marashi and Davis, 2006, Marashi and Davis, 2005, Marashi and Davis, 2004, Hall, Blockley and Davis, 1998, Davis, MacDonald and White, 2010) and Agent Based Modelling and Simulation (Bryson, Ando and Lehmann, 2007, Lorenz, 2009, Moretti, 2002). There are many others. This debate is also not prominent in the SSM literature – possibly because such modelling is based strongly on functionalist, hard systems thinking which attempts to model the behaviour and response of actual systems. Although (Checkland, 2010) does talk about the "*soft*" approach not throwing away the "*hard*" thinking but *subsuming* it as a special case within the broader approach.

Jackson argues strongly against modelling approaches from the functionalist paradigm straying into soft-systems territory (Jackson, 2003). For example stating that in the case of system dynamics that it risks "*becoming an under-theorised soft systems methodology*". However, Lane and Oliva argue, convincingly we believe, that a "*synthesis*" of system dynamics and SSM can bring "*dynamic coherence*" to SSM (Lane and Oliva, 1998). However, they do draw attention to the need for theoretical consistency. We could generalise this need for *careful* synthesis to examples such as hierarchical process modelling where it would be used to bring *risk and uncertainty coherence* to a PSM and so on. The argument presented by Kotiadis and Mingers is encouraging although the message is still being digested as a practical way forward for us (Kotiadis and Mingers, 2006).

The issue is partially tackled by the idea of multimethodology (Mingers, 2001, Taket and White, 1998) although the integration here is of problem structuring methods, or parts of these methods, and not the focus in this paper of bridging from *research* methods and towards use of a soft systems approach by engineers. However (Mingers, 2001) talks of intervention as a process and usefully provides a description of 4-phases that are important at different points in time (Appreciate, Analyse, Assess and Act). This idea is summarised in Figure 2 and seems ideally suited to the way in which engineers think and behave. It is the Appreciation phase in Mingers schema that most closely overlaps with the process of using research methods we discuss in this paper.

Figure 2. Phases of PSM intervention adapted from (Mingers, 2001).

We also express the need in engineering that appropriate longitudinal studies need to be integrated as well in order to provide the necessary framework for measurement and monitoring. Thus whilst Figure 2 provides a useful schema with the explicit representation of time it still presents a *one shot* view of intervention. We believe that an iterative approach needs to be made explicit and that the action research spiral of (Kemmis and McTaggart, 2000) shown in Figure 3 provides a better conceptualisation of time.

Figure 3. The Action Research Spiral adapted from (Kemmis and McTaggart, 2000).

This has led us to a propose a synthesis of (Kemmis and McTaggart, 2000) and (Mingers, 2001) structured around the use of purposeful activity models as a summarising schema for our work and is shown in Figure 4.

Figure 4. Proposed schema for research method and PSM integration based on an integration of ideas from (Rittel and Webber, 1973, Mingers, 2001, Checkland, 1999, Kemmis and McTaggart, 2000) and needs of the Systems Practice in Engineering (SPiE) project.

In this context, we are currently engaging Research Engineers and ourselves with three key questions to help in encouraging wider adoption of a soft systems approach by engineers as follows:

1. Any purposeful activity model, although not representing the real world, cannot be developed in a vacuum and must presumably draw on the observer's experience of the real world – and maybe *best practices* experienced elsewhere or enshrined in codes, procedures etc. So, to some extent the PA/holon must have elements of real world thinking within it – and represent (possibly) a real world existing in another setting?
2. Any agreed action to improve as a result of a soft system study has the intention of drawing the idealized purposeful activity model and real world system closer together. Therefore how is progress towards this ideal measured and monitored?
3. Bearing in mind that any initial action from a soft system study is likely to be the first in a *roller coaster*, or spiral, journey towards a solution involving several sequential interventions (particularly in a dynamic system) - some way of *capturing* the learning from the outcomes of these sequential interventions – to inform debate about the next phase would seem important. In other words, do we not need also to emphasise the continual learning and adaptation function of modelling to capture new knowledge as it emerges after interventions? A need similar to this is described

by (Mingers, 2001) where he describes approaches to partitioning and decomposing methodologies.

6.3. Debate on the preferred intervention option

In the third stage of SSM, the decision on which change or intervention option is to implemented and getting "*permission to move*" is presented as being based mainly on "*debate and negotiation*" – hence the need for engineers to develop appropriate and practical skills in leading and managing change.

However, more detailed research and data gathering/analysis may be needed at that point also – e.g. using ethnographic, grounded theory or survey strategies to gather and interpret more facts within the problem setting, inform the debate and where necessary help individuals to adjust world views based on facts and new appreciations of what appears to be going on. Thus, understanding of when to trigger additional research in the later stages and the ability to negotiate and convince others of the benefits of the extra time needed (to better inform the debate) are crucial. If undertaken, additional research should adopt appropriately sound and rigorous ways of gathering and analysing (mainly) qualitative data. Techniques and skills in e.g. questionnaire development, interview planning and design of focus groups are central to this and covered in our research methods teaching. Following this, the skills in qualitative data analysis such as computer methods, content analysis and discourse analysis of interview transcripts are required in order to objectively inform the debate.

During this stage – a basic model for considering ethics when considering interventions is also required – in order for the chosen intervention to be fully "*desirable and culturally feasible*". Classical SSM does not give high prominence to ethical considerations although the words in main activity C could be taken to imply this. A full understanding of ethics frameworks and managing decision-making, change and intervention in such situations is important. Ethical matters can involve harm, consent, privacy, confidentiality etc. and decisions may need to align with the ethical framework of a University, Company or sponsoring organisation as well as individual stakeholders. Engineers have explicit obligations for ethical behaviour placed on them by their chartering body (e.g. the Engineering Council in the UK) and these need to be carried forward into areas of practice where purpose and even agreement on what counts as a successful outcome may be contested. A systemic perspective on this is beginning to be taught to engineers, for example through (Elliott, 2006).

Since SSM is action research, understanding and managing the potential downside (risk) of any planned intervention in a complex system is a crucial aspect at this stage and which is often not given sufficient prominence. In broad terms, and using the Cynefin framework of (Kurtz and Snowden, 2003) as a framing device, the risk can be associated with driving the real system/problem situation from the complex into the *chaotic* region of the complex problem space. Risk identification and management techniques, including slowing down, limiting or excluding otherwise acceptable interventions in the final stage are important.

6.4. Taking action in the problem situation to bring about improvement

Here, the idea that a complex wicked problem is never *solved* – but continually *resolved* is important. In other words, the concept that a single intervention will represent the ultimate solution in a complex problem situation does not often accord with reality. In this case need for appropriate performance measurements is apparent together with the necessary longitudinal studies – especially if the project is to be handed on to the next researcher. Given that system boundaries are always open to investigation it is important that some degree of consistency in the definition and measurement of meaningful performance indicators is ensured.

The research journey in addressing complex problems as discussed in §3 and covered in our research methods teaching using the original Rittel and Webber concept (later taken up by (Conklin, 2001)) that problems are never solved, but continually re-solved in a roller coaster sense by trialling successive solutions and learning at each stage.

SSM – as presented above – does not emphasise this (often required) cycling aspect after the first intervention - and the need for models to be developed which allow learning at each stage based on data gathered after an intervention. In fact, we believe SSM sometimes encourages something of a *one shot* picture. This partly reflects its consultancy background. This cycling aspect of SSM needs careful discussion since it may take the full project beyond the duration of a typical 4 year EngD in Systems research project (or indeed any PhD) – without the problem having been addressed satisfactorily.

6.5. Summary

Based on these 4 strands of discussion we can see that there is a clear need to support the introduction of a soft systems approach with rigorously selected and applied basic research tools for them to meet the needs of the EngD in Systems Programme, given the scope of the projects at the boundary between hard systems and the social world and grounding in engineering. We support Checkland's idea that SSM is equally capable of identifying desired interventions/changes in hard systems (engineering artefacts, products etc.) as well as human activity systems (organisational arrangements, work processes etc.) and that this is a message to take back into the *traditional* Systems Engineering community for further examination. Our summary proceeds through a series of questions that arise from our analysis.

6.5.1. Skills

The skills training of engineers needs to be examined. If a soft systems approach is to be applied in an EngD in Systems research project, can the researcher realistically be trained to be and/or act as the *facilitator* as well as a contributor to the process? The skill of facilitation is not trivial and relevant training becoming an essential component in the further development of the EngD in Systems Programme (Wilmshurst and Terry, 2012). This reference includes a link to a video in which Wilmshurst and Terry provide in-depth explanations of how needs are driving this skill development component. We are confident that this provides a useful generic approach but is not yet focussed on specific PSM training, for example like that developed by Hindle for SSM (Hindle, 2011).

6.5.2. Modelling approaches

The contribution of diverse modelling approaches needs to be examined. Is CATWOE enough as a basis for checking the quality of a conceptual model and root definition of a system? Should a more detailed and *learning-based* check be used – for example inclusion of system inputs/outputs, and possible system categorisation such as archetypes from systems thinking (Senge, 1990)? In other words, do we need a better steer for engineers for developing the best conceptual models and root definitions?

6.5.3. Iteration

Many cycles of a soft systems approach may be needed in a real world situation to move to an *acceptable* solution to a wicked problem. Should we emphasise this more in our teaching of all systems approaches and what sort of implications might this have for a real EngD in Systems research project e.g. is identification of the first action or intervention alone and implementation of this enough in a research project? This may not satisfy the industrial sponsor of the project.

6.5.4. Informed debate

We believe that it is crucial to base the identification and selection of the preferred intervention in the later stages of a project on appropriate rigorous research as well as informed debate. More detailed research (under both phenomenological and positivistic paradigms – survey, experiment, ethnography…) may be needed in the later stages to inform such a debate. Otherwise this may take the form of a highly biased choice driven by seniority, politics and dominant personalities and hierarchies? The basic SSM approach is lacking in that it can ignore questions of power and hierarchy among actors and the researcher may well be too junior to handle the process. The question of how emancipatory approaches might be used within the programme is still completely open.

6.5.5. Managing risks

How should a Research Engineer develop an appreciation of and manage the risks involved in any first trial intervention resulting from using a soft systems approach? How do we cover this in our teaching and give researchers an appropriate toolkit? Should it be part of managing change? The same is also true for ethical considerations.

6.5.6. Intervention

Implementation of an agreed intervention resulting from a soft systems approach could potentially lead to a major project in its own right – based more on hard systems methodologies and agreed objectives/measures etc. and subsequent performance measurement/management. This demands different skills and may take too long beyond the timescale of an EngD in Systems research project? If a researcher takes on a full blown soft systems strategy, should they be encouraged to stop at the point where an intervention is agreed and a performance measurement plan is developed?

6.5.7. Deciding success

To traditional engineering managers, a soft systems approach can come across as open ended and difficult to manage – and unlikely to be judged a complete success or complete failure. Also, it is often presented as a process where the human interactions and debate are as, or more, important than the result. How do we accommodate this view, which we believe is largely correct, and turn it to an advantage? Since SSM is a strategy for intervention based on a phenomenological, interpretivist paradigm, it aligns with all such strategies in terms of being highly valid, but low on reliability and producing results which are normally difficult to generalise to other settings. How do we ensure this aspect is fully understood by industrialists with a strong engineering management focus?

6.5.8. Change management

The principles of change management are crucial to engage with when implementing and managing the introduction of an intervention resulting from a soft systems approach since successful change management is the way for the intervention to result in outcomes that then result in the envisaged benefits. So outcomes and benefits modelling are important as a part of change management. But leading and managing change *during* a soft systems approach is arguably equally important and relates to the skills and background of the facilitator/consultant just as much as knowledge of the method. For example, helping change world-views of the actors and supporting update and change of mental models.

6.5.9. On becoming expert

Key's observations on "*becoming expert*" in the use of PSMs provide a useful lens to view our own perspective of bringing about wider adoption of soft systems approaches in engineering (Keys, 2006). The constructs reviewed by Keys to first distinguish expert from novice (summarised in Table 1) and then to map out the journey from novice to expert are generic and apply to more than the PSMs, which are the subject of his paper and are just as applicable to engineering expertise and perhaps more rigorously articulated in the requirements to cross the threshold classified as Chartered in the UK. Keys poses three questions the need to be answered, i) how to codify the "*intuitive and hidden*" yet familiar knowledge that an expert uses which is beyond the explicit and public knowledge about a PSM that is necessary to make it work as an effective intervention, ii) understanding what variables in the problem context determine whether a particular PSM is likely to be successful, and iii) appreciating how working at the boundaries of ability and applicability will lead to enhanced expertise by the very nature of dealing with "*tough and atypical*" interventions? We can answer question two competently, we already use frameworks such as Jackson's System of Systems Methodologies (Jackson and Keys, 1984, Jackson, 2010, Jackson, 1993) and Minger's classification of philosophical assumptions of MS methods (Mingers, 2003) in teaching on the EngD in Systems Programme. We can only exhort Research Engineers on the Programme to *start* using a soft systems approach, because without that first step they will always be novice. However, assuming that the journey from novice to expert has been started, and that knowing when it is appropriate by context to start has been answered then it seems that our challenge is accessing the *"intuitive and hidden"*, which seems to be a generic problem, not just limited to engineers' use of the methods.

7. CONCLUSIONS

We believe that integration of appropriate basic research methods and tools with soft systems approaches is important from the viewpoint of academic requirements in Doctoral level engineering systems research. But equally importantly, integration is valuable from a practitioner viewpoint in a socio-technical engineering context in order that a system intervention resulting from a soft systems approach can be fully justified, is evidence-based, the logic is recoverable by others, and a robust platform is created for any subsequent interventions and sequential action learning.

Our conclusions based on the analysis in this paper, are expressed as a set of desirable activities that engineers need to focus on. We present them here as a list of 10 elements with explicit use of a verbal noun (gerund) formulation to convey component activities (action or state of being) of this purposeful activity of *bringing about* the wider user of soft systems approaches in engineering systems and consistent with our approach of using a process-oriented view.

1. Making active use of the widest range of techniques and tools for initial investigation of a complex problem situation, spanning rational and creative approaches,

2. Adopting an early definition and consideration of a suitable ethics framework and ethical questions that may need addressing to effectively manage decision making, change and intervention for it to desirable and culturally feasible,
3. Taking careful consideration of the most effective approaches for creating root definitions and representations of purposeful activity models (holons) in order to stimulate debate in an engineering culture on beneficial changes or interventions in the system,
4. Broadening the concept of modelling to include the progressive synthesis of harder, more advanced predictive modelling approaches, most commonly used under a functionalist paradigm, to capture learning and new knowledge (e.g. as generated from simulations),
5. Considering the potential need for additional detailed research and data gathering at the point where initial intervention options are being debated, in order to inform the debate and underpin principled negotiation,
6. Applying appropriate tools and processes for understanding, and managing the potential downside risk of any planned intervention, guarding against system performance deterioration and/or increased chaotic aspects,
7. Appreciating the need for modelling approaches to be capable of capturing learning arising from *roller-coaster* type journeys towards a solution involving cycles of sequential interventions (a *spiral* journey*),*
8. Addressing the need for appropriate and consistent system performance measurements or metrics to be defined together with longitudinal studies to measure improvement and benefits,

9. Ensuring all stakeholders are fully aware of the relationship between outcomes from SSM and any later change processes which must be completed in order for outcomes to be translated into improvements and benefits,
10. Clarifying, particularly in the 'hard' culture of an engineering organisation, the fact that SSM can give highly valid results, but generally these are relatively unreliable and difficult to generalise to other systems or settings.

8. Acknowledgements

This research was supported in part by the EPSRC Industrial Doctorate Centre (IDC) in Systems (EP/C537556/1 and EP/G037353/1). We are grateful to the anonymous reviewers who have provided much insightful comment and helpful suggestions on the original and revised versions of the paper and which has led us to a better articulation of what we now see as the core problem – that of bringing about the wider adoption of soft systems approaches in engineering systems.

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PHILOSOPHICAL ASSUMPTION	POSITIVISM	PHENOMENOLOGY
Ontological assumption (the nature of reality)	Reality is objective and singular, separate from the researcher	Reality is subjective and multiple, as seen by different stakeholders
Epistemological assumption (what constitutes valid knowledge)	Researcher is independent of that being researched	Researcher interacts with that being researched
Axiological assumption (the role of values)	Research is value free and unbiased	Researcher acknowledges that research is value-laden and biases are always present
Rhetorical assumption (the language of research)	Researcher writes in a formal 'professional' independent style, uses the passive voice, accepted quantitative words and precise definitions	Researcher writes in an informal style, uses the personal voice and conveys the idea that they have 'interacted' with and are part of the research. Accepted qualitative terms are used and limited definitions.
Methodological assumption (the process of research)	Process is deductive Study of cause and effect Static design Categories defined and isolated beforehand Research is context free Generalisations lead to prediction, explanation and understanding	Process in inductive Study of mutual, simultaneous shaping of factors Emergent design Categories identified during the process Research is context bound Patterns and theories are developed for understanding

Table 1. Comparison of philosophical assumptions for positivistic and phenomenological research. Adapted from (Collis and Hussey, 2009).

PROBLEM SITUATIONS SOME INVESTIGATION TECHNIQUES	
Rational	**Creative**
System/influence diagram	Rich pictures
Preliminary literature review	Metaphors and analogy
Interviews	5WH group questioning
Critical incident analysis	Brainstorming
Morphological analysis	Focus groups
Relevance system diagrams	Lateral thinking (De Bono)
Cognitive mapping	Delphi method
Ishikawa diagrams	Quality circles
Preliminary modelling	Cross professional learning
Preliminary data analysis	Future state visioning
Stakeholder analysis	

Table 2. Comparison of rational and creative investigation techniques. Adapted from (Saunders, Lewis and Thornhill, 2009).